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ANALYSIS OF COOLANT TEMPERATURE AND SWIRL MOTION EFFECTS ON CYCLE TO CYCLE COMBUSTION VARIATIONS IN SI ENGINE USING REGRESSION AND CORRELATION TECHNIQUES

V. KRISHNAMOORTHY

Professor, Department of Mechanical Engineering, Saveetha Engineering College, Chennai, Tamil Nadu, India

ABSTRACT

The improvement of exhaust emission and engine performance in terms of fuel economy depends on the understanding of combustion process in IC Engines on cycle to cycle basis. It also helps to improve engine stability. Two port injected SI engines were analyzed for cycle to cycle variation in combustion to know the effect of initial combustion processes on the following combustion. For different equivalent ratios the correlation between IMEP and pressures almost showed same trends but with different mixture preparations indicated different tendency. With two engines for the given referenced angles the dependency of IMEP on pressure increases when mixture becomes leaner. By deactivating one intake valve and by varying the coolant temperature, mixture distribution in the combustion chamber was varied due to air motions and evaporation of fuel. With the Coolant temperature and air motion, correlation between pressures related parameters were done.

KEY WORDS: IMEP, Correlation, SI Engine, Cold Start, Swirl, Cycle to Cycle Variations & Coolant Temperature

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Original Article

INTRODUCTION

There are various factors such as type of fuel, Air fuel mixture motion, residual gases and mixing of air and fuel, causes cycle to cycle variation in combustion process though the IC engine may be under steady state condition of operation with respect to load and speed (Ozdor, N, 1994). Other factors such as location of spark plug, spark strength and heat dissipation in the electrode also contribute greatly to the cycle to cycle variation of combustion parameters in Engines (Bates, 1989). These cyclic variations are excessively demonstrated by the engine when cold starting, idling and lean mixture operations.

Combustion parameters such as flame propagation and pressures can be analyzed to know the cycle to cycle variations in IC Engines. The variations in Combustion process can greatly be studied by visualizing the flame propagation with the help of high speed vision equipment and laser diagnostics. (Keck and Heyward, 1987) But with the help of measurement of Combustion pressure, the variation in combustion process can be easily analyzed. Combustion pressure measurement also helps in detecting misfire, knocking and also to achieve efficient operation of IC engines by spark timing optimization. (Spicher and Backer, 1990). Cycle to cycle variations in Combustion process can be confirmed by measuring combustion pressure thereby evaluating the combustion state (Young. M 1981). It is imperative to understand how the initial combustion state affects the later combustion process and there by engine performance, so as to improve the engine stability. In this Research the effects of previous cycle's combustion on successive cycle's combustion were analyzed for different air-fuel mixture and the

coolant temperature with the pressure data. Two different spark engines with the port injected fuel system were compared to have consistency in study.

EXPERIMENTAL PROCEDURES

Figure 1 shows the experimental setup in schematic sketch. Piezoelectric pressure transducer Kistler 6053CC was mounted in the cylinder head to measure the combustion pressure and analyze the combustion process. The pressure data were sampled at a rate of 1^o CA (Crank angle) intervals for 100 cycles in the data acquisition system and processed to obtain the pressure at referenced Crank angles and IMEP (Indicated Mean Effective Pressure). To measure air-fuel ratio, laminar flow meter and exhaust gas analyzer were used. The specifications of two different four stroke SI (Spark Ignition) engines are given in Table 1. The tests were conducted with fueling and spark timing controller, Dynamometer controller, encoder, Throttle actuator, ECU (Electronic control unit) and computer. For consistency two different SI Engines were used for experiments. To study the effect of fuel vaporization and mixing at low temperature conditions, the engine coolant temperature of engine A were changed. In engine B, one intake valve was deactivated to induce higher swirl in the combustion chamber and change the mixture distribution in the combustion chamber.

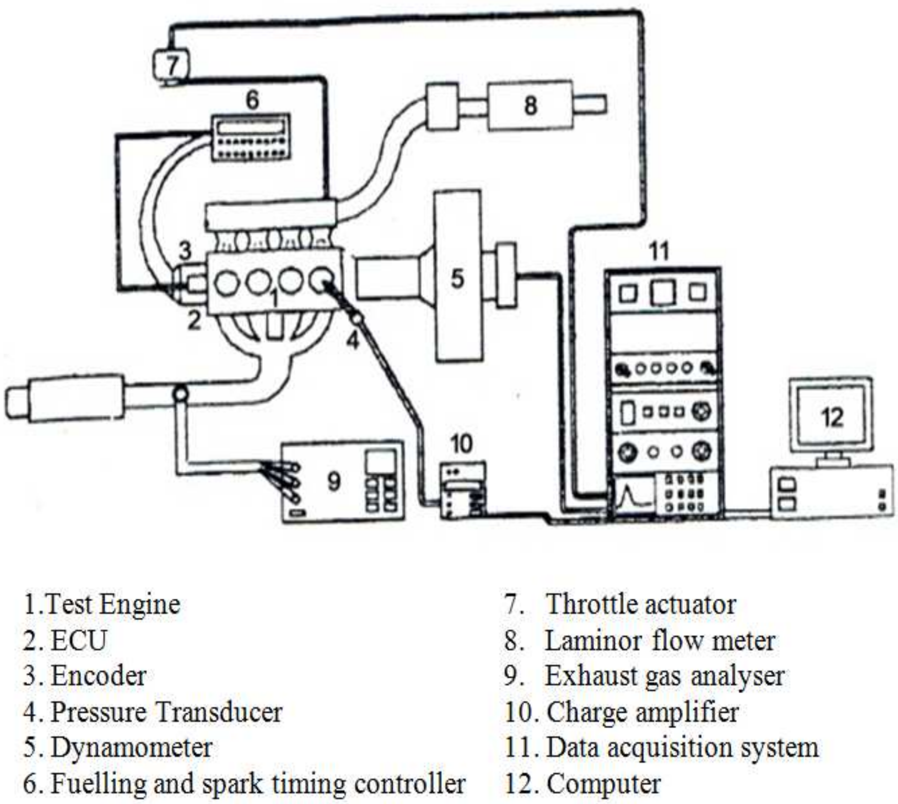

Figure 1: Schematic Diagram of Experimental Setup

Table 1

	Engine A	Engine B
Bore (mm)	75.5	82.0
Stroke (mm)	83.5	85.5
Swept Volume (cc)	374	448
Compression Ratio	9.5:1	10:1
Valve Timing	5/35 43/5	9/43 50/6

The two engines were operated at some specific part load conditions, that is 2000 rpm / 2.0 bar BMEP (Brake Mean Effective Pressure) for engine A and 1500 rpm / 2.0 bar BMEP for engine B. To study the coolant temperature effect on combustion variation, two different engine operating conditions were employed. One with idling condition during warming up period in which the engine speed and mixture ratio were varied as the operating time elapsed. Another with the fixed engine speed, intake pressure and fuelling was applied. The data was analyzed to understand the effect of fuel evaporation on Cycle to cycle variations in combustion process. The conventional statistical method of regression for correlating the two variables and covariance are applied in this research work. (Ref 6: Dunn & Clark, 1997).

RESULT & DISCUSSIONS

Variation in Pressure at Referenced Crank Angle

With referenced Crank angle the pressure variations were compared to validate the effect of initial combustion pressure as parameters for cycle to cycle variation in combustion.

The variation in cylinder pressure for entire cycle is represented by the standard deviation divided with mean pressure at referenced crank angles. In Figure 1, variations in cylinder pressure in terms of percentage at referenced crank angles were shown for different equivalence ratios. The variation in pressure at referenced crank angles when the engine is not firing i.e at motoring condition is only 0.2 – 0.3 % but during firing conditions the variation in pressure is substantial.

CA_{ppeak} in the Figure 2 means crank angle at which the peak pressure occurs. At 15^0BTDC (Before Top Dead Centre) the variation in pressure is around 1.4% for equivalence ratio of Z = 1.0, which is slightly higher than the variations in pressures of motoring conditions. The probable reasons attributed for this small variation is the lack of time for combustion after ignition initiation.

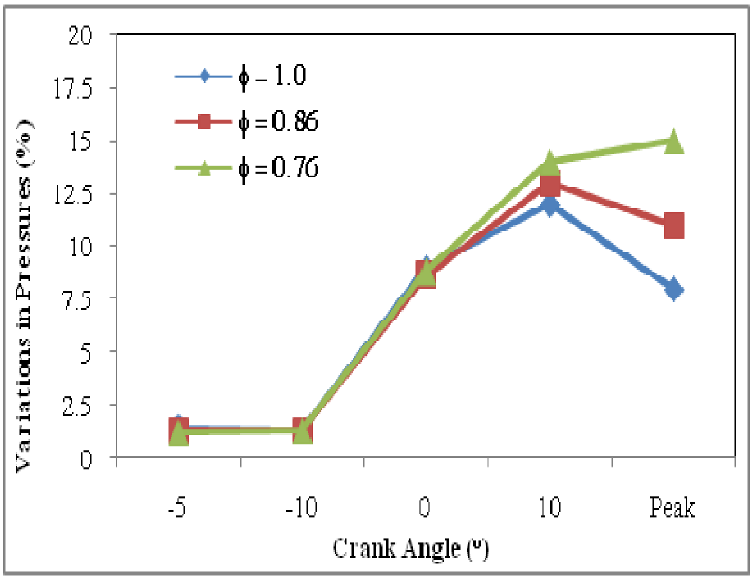

Figure 2: Variations of Pressures at Referenced Crank Angle for Different Equivalence Rates

It is very evident from the Figure 2 that as the combustion progresses, the variation in pressure also increases rapidly and also the leaner mixture operation is prone for higher variation in combustion pressure than the stoichiometric condition, implying unstable combustion with leaner mixture.

Correlation between Pressures at Referenced Crank Angles

The dependence of later stages of combustion on the early portion of combustion was investigated to assess the validity of initial combustion pressure as parameter for cycle to cycle variation in combustion. Figure 3 shows the effect of pressures at 15^o BTDC on latter pressures for different equivalence ratios. It is seen from the figure 3 that the pressures at 10^o BTDC show a higher dependence on pressures at 15^o BTDC. On the contrary later pressures at TDC (Top Dead Centre), 10^o ATDC (After Top Dead Centre) and 20^o ATDC don't show any correlation with the initial pressure. Hence it can be concluded that combustion after TDC is not affected by the very early combustion state. However, the correlation between the pressure at 10^{o}BTDC and later pressures indicate relatively increased tendency as indicated in Figure 4. As the mixture becomes leaner, the correlation coefficient improves but when the combustion proceed further for all operating conditions these correlation coefficient decrease linearly and becomes less significant after TDC. From these trends of correlation coefficient it is seen that the combustion is accelerated as the combustion proceeds, and cycle to cycle variation in combustion diminishes to a lesser value. It is presumed that the inhomogeneous mixture distribution in combustion chamber due to port injection is not affecting much the subsequent combustion.

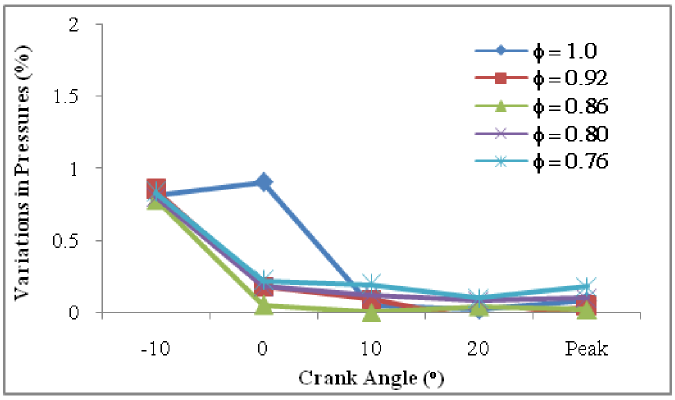

Figure 3: Correlation for Combustion Pressures with Pressure at 15^o BTDC

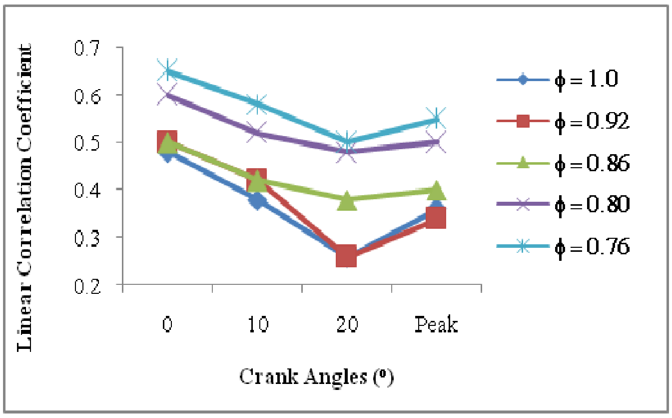

Figure 4: Correlation for Combustion Pressures with Pressure at 10^o BTDC

Correlation between Pressure and IMEP

The Correlation between IMEP and pressures at referenced crank angles are analyzed as presented in Figure 5 in which R means the linear correlation coefficient, there by confirming the effect of combustion pressure on IMEP.

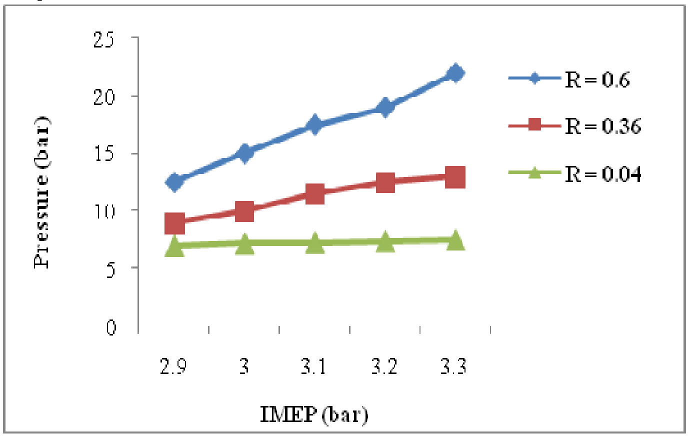

Figure 5: Correlation between IMEP and Pressures for Equivalence Ratio ϕ = 1

The linear correlation between pressure and IMEP for different mixture ratios at referenced Crank angles are shown in Figure 6. It is evident from the Figure 6 that the correlation coefficients are increased as the combustion proceeds irrespective of mixture ratios. Hence IMEP is more closely correlated with the later pressures than the initial pressures. As the pressure at the referenced crank angle increases, the IMEP also increases. In leaner mixture operations, the correlation coefficient increases, implying IMEP is more dependent on the later stage of combustion.

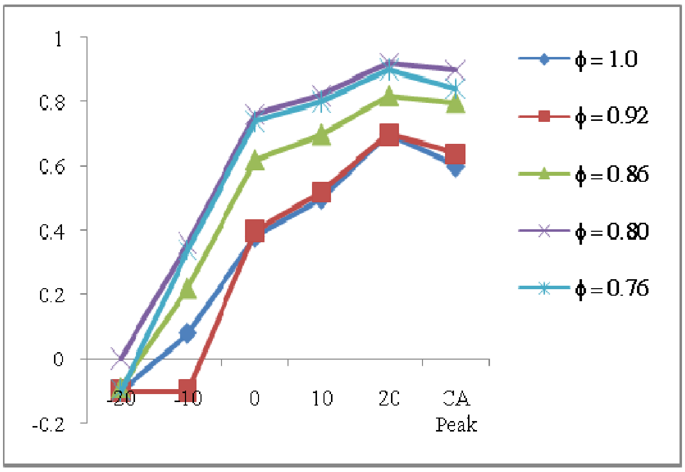

Figure 6: Correlation between IMEP and Pressures for Various Equivalence Ratios

Effect of Coolant Temperature on Correlation Coefficient

During the warming up period the level of variation in pressures at specified crank angle is changed with the coolant temperature and it is also seen that the variations in pressure at specified crank angles increases as the combustion progresses. Figure 7 shows the variations of pressure corresponding to the Crank angles and coolant temperatures. It is clear from the figure 7 that variation in combustion is higher with the low coolant temperatures. It is difficult for the fuel to evaporate at low coolant temperature and hence more liquid fuel is induced into the combustion chamber causing mixture in-homogeneity. The cycle to cycle variation in mixture distribution also seems to be increased. Hence variation in combustion is due to variation in pressures caused by mixture ratio variation, in-homogeneity and cycle to cycle variation in mixture distribution.

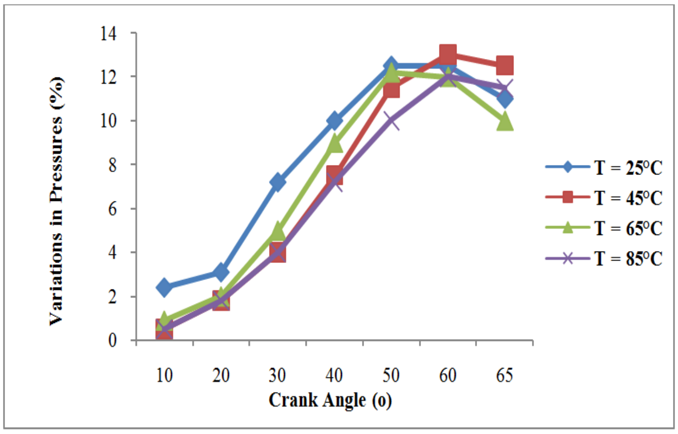

Figure 7: Variations of Pressures at Idling with Different Coolant Temperatures

The effect of initial combustion on later stage of combustion during warming up period is examined in Figure 8. The trend of correlation shows almost same as normal operating condition for increased coolant temperature. However with low temperature of 25^0C, the effect of initial combustion is relatively poor. This implies that the mixture distribution at cold start is more inhomogeneous and the initial combustion is not sufficient due to difficulty in fuel evaporation. At idling condition another peculiar phenomenon is that the crank angle at which maximum pressure occurs is very close to the TDC.

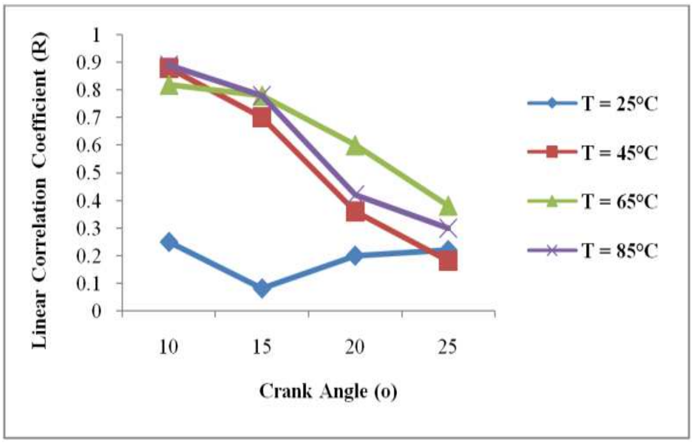

Figure 8: Correlation between the Pressure at 5o ATDC and Coolant Temperatures During Idling Condition

Due to the retarded spark timing, the crank angle at which the peak pressure occurred should be retarded, but this angle appeared very close to TDC. The reason for this is that the slow combustion is dominant in the peak pressure occurring at idling.

The effect of coolant temperature on the IMEP dependency on the pressure at specified crank angles as shown in Figure 9. This trend is nearly same as the fully warmed up condition; however the case of 25^oC indicates relatively less correlation than the higher coolant temperature cases.

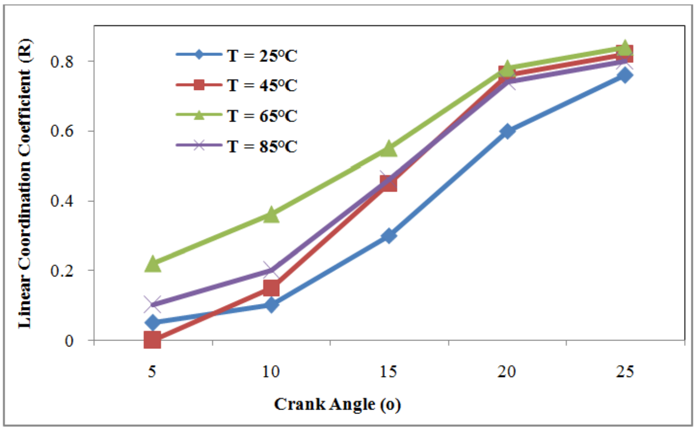

Figure 9: IMEP Dependency on Pressures at Crank Angles with Coolant Temperature During Idling Condition

By keeping the fixed engine speed, intake pressure and fuelling at the part load condition, the effect of fuel vaporization on cycle to cycle variation was studied. In this case, with the lower coolant temperature the correlations between initial pressure and later pressures are very poor and only the case of 85°C show relatively higher correlation as the normal operating condition as shown in Figure 10. In Figure 11, the correlation does not exist appreciably except for the case at 85°C as the combustion proceeds.

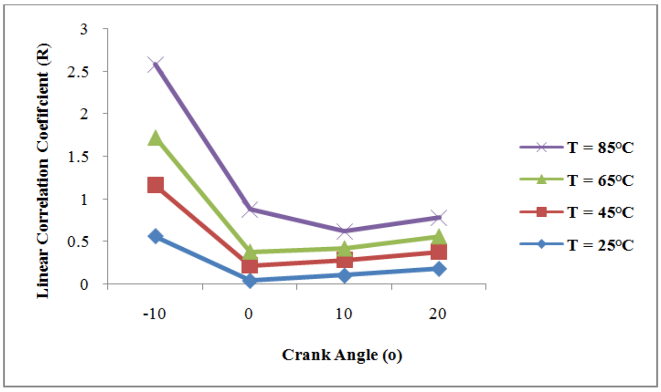

Figure 10: Correlation Between the Pressures at 15° BTDC and Later Pressures for Part Load Condition for Different Coolant Temperature

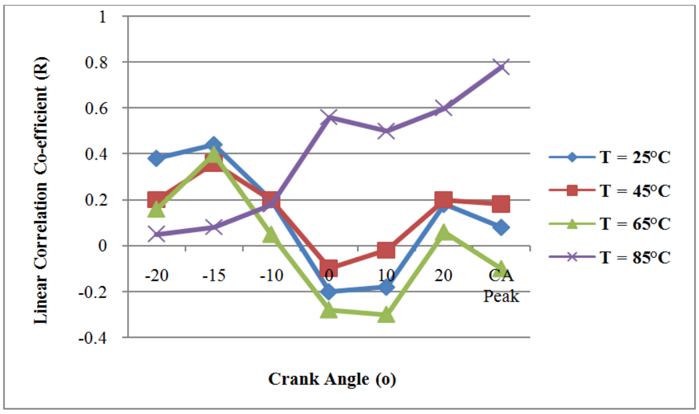

Figure 11: IMEP Dependency on Pressures at Crank Angles for Various Coolant Temperatures During Part Load

Effect of Air Motion

The engine B was operated with one deactivated intake valve to know the effect of intake air motion on cycle to cycle variation in combustion. As one valve is deactivated, the swirl motion in combustion chamber is increased there by affecting the mixing of air and fuel and their distributions. From Figure 12, it is evident that as the mixture goes leaner, the pressure variation increases. When both the valves are active, the swirl level is low and for equivalence ratio of 0.91 the variation in combustion pressure is relatively higher than the rich mixture as shown in Figure 12 (a). When one intake valve deactivated, the swirl motion is high but trend of variation in pressure is same as in the case of low swirl motion as shown in Figure 12 (b). Comparing the Figures 12 (a) & (b), it is evident that the pressure variation is higher for high swirl motion before TDC than for lower swirl motion. Whereas after TDC the variation in pressures is lower due to the faster combustion with increased swirl motion.

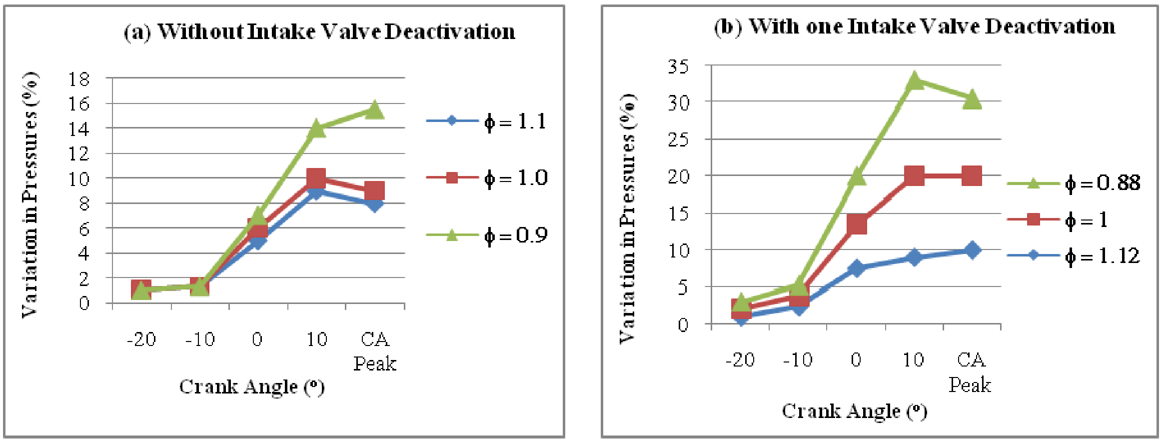

Figure 12: Variation in Pressure for Engine B with Swirl Variation for Crank Angles

The Coefficient of variance (COV) in IMEP indicates that the cycle to cycle combustion variation is more stable for higher swirl motion as shown in Figure 13 (a) & (b). When the mixture is lean, the effect of swirl on combustion variation is predominant as COV in IMEP for Z =91 with one intake valve deactivation is 3.2% whereas it is 6.1% for other engine. The IMEP with rich mixture decreases in the early combustion as the initial pressure increases. This is because the initial combustion is faster due to the increased turbulence.

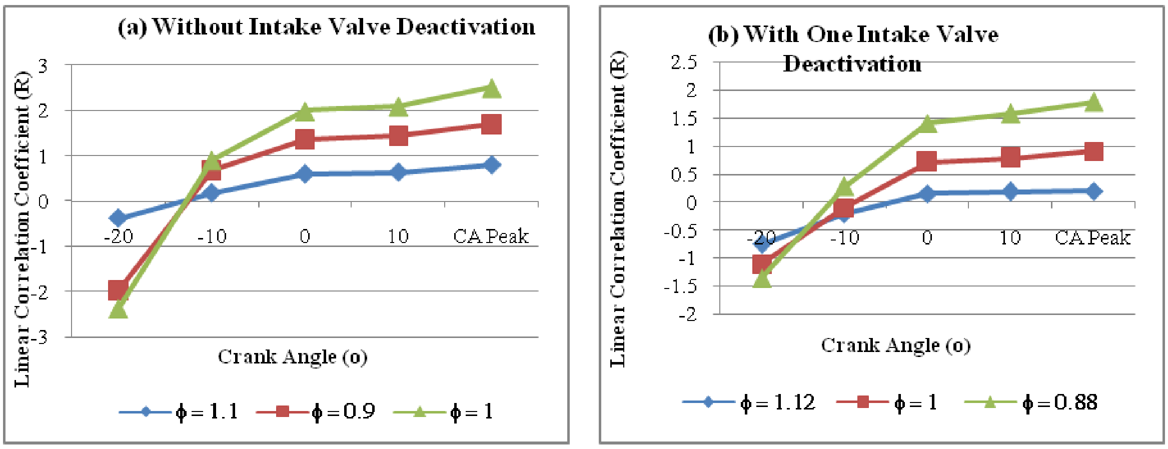

Figure 13: Correlation between IMEP and Pressures for Engine B for Crank Angles

CONCLUSIONS

The effect of engine coolant temperature and air motion on cycle to cycle combustion variation is very evident. As the combustion proceeds, the variation in pressure increases at the referenced crank angle. This variation in pressures increases with leaner mixture and with lower coolant temperatures. The pressures at specified referenced crank angle generally showed good correlation to each other. In port injection, the subsequent combustion is less affected by the early combustion due to less uniform mixture distribution in combustion chamber.

The correlation between IMEP and pressures at crank angles increases when the mixture is lean and on the contrary this correlation is poor at low coolant temperature but increases as the engine warms up. However, the increased swirl motion due to one valve deactivation makes combustion more stable and dependency of IMEP on pressures show different trend in early combustion with rich mixture.

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